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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 710

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TESTS FOR THE ELIMINATION OF TAIL FLUTTER

By Curt Biechteler

Zeitschrift für Flugtechnik und Motorluftschiffahrt
Vol. 24, No. 1, January 14, 1933
Verlag von R. Oldenbourg, München und Berlin

Washington
June, 1933

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TESTS FOR THE ELIMINATION OF TAIL FLUTTER*

By Curt Biechteler

I. INTRODUCTION

On various low-wing monoplanes the horizontal tail surfaces flutter in flight at large angles of attack and occasionally in curvilinear flight. This flutter leads to torsional vibrations of the rear end of the fuselage, as manifested by vibrations of the control stick. In some cases tail flutter reaches such amplitudes as to affect the strength of the horizontal tail surfaces and of the rear part of fuselage.

According to earlier D.V.L. (Deutsche Versuchsanstalt für Luftfahrt) investigations with various airplanes and airplane models of the Junkers F 13 type (reference 1) tail flutter is due to the influence, on the horizontal tail surfaces, of eddies or vortices shed at large angles of attack by the upper surface of the wing root.

The cause of tail flutter on a low-wing monoplane and the means of preventing it are investigated in the present report.

II. INVESTIGATION OF THE CAUSE OF TAIL FLUTTER

1. Test Procedure

A BFW-M 23 b airplane (figs. 1 and 2) was used for the investigation of the cause of tail flutter. Flutter of the horizontal tail surfaces occurred on this airplane in leveling off prior to landing and in curvilinear flight. The landing characteristics were greatly impaired by the fluttering. The disturbed flow about the horizontal tail surfaces caused a slight oscillation of the airplane about

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*"Versuche zur Beseitigung von Leitwerkschütteln." Z.F.M., January 14, 1933, pp. 15-21.

the transverse axis in flattening out. These longitudinal oscillations had to be balanced by alternate elevator deflections, the pilot being thus compelled to "pump" in landing.

Red woolen threads of approximately 20 cm (7.9 in.) length were fastened to the upper surface of the left wing to indicate the flow about the wing. The distribution of the points of observation is shown in figure 3. The woolen threads and the tail unit were observed in straight, curvilinear and spiral flights and in sideslips. Each of these maneuvers was made at full throttle and also with idling engine.

2. Results

In straight flight with idling engine the threads near the fuselage were greatly disturbed at all impact pressures. Even at very small angles of attack a separation of the flow was observed in this region. The horizontal tail surfaces were quiet at speeds above 110 km/h (68 mi./hr.).

With decreasing impact pressure the separation of the flow spread out fanlike from the wing root to the tips. Tail flutter began at a speed of 110 km/h. When fluttering began, the stabilizer tip had a double amplitude of 2 cm (0.79 in.) which increased to about 4 cm (1.6 in.) at 85 km/h (53 mi./hr.). ($c_a = 1.4$) The vibrations were transmitted by the rear end of the fuselage to the vertical tail surfaces. Their double amplitude at the tip of the fin was half that of the stabilizer tip.

The extension of the region of separation with decreasing speed in straight flight with idling engine is shown in figure 3. The boundary between the adhering flow and incipient separation spreads out fanlike with decreasing impact pressure from a point forward of the leading edge near the fuselage.

In straight flight with full throttle, the flow about the wing was only slightly disturbed near the fuselage at speeds down to 110 km/h. Tail flutter began at 90 km/h (56 mi./hr.). The amplitude of vibration of the stabilizer tip at 90 km/h was approximately 2 cm (0.79 in.) and reached 3 cm (1.2 in.) at 85 km/h (53 mi./hr.). As in straight flight with idling engine, the region of disturbed flow spread out fanlike with decreasing flight speed. The displacement of the boundary of the region of separation with decreasing speed in straight flight with full throttle is shown in figure 4.

In right and left turns with full throttle and idling engine the tail unit was quiet as long as the turns were correctly flown, the bank of the airplane corresponding to the radius of the turn. Slipping or squashing caused pronounced tail flutter (double amplitude 4 to 6 cm (1.6 to 2.4 in.)), irrespective of the impact pressure and of the engine r.p.m. The same observation was made in right and left spiral flight with full throttle and with idling engine. Sideslips immediately resulted in the fluttering of the horizontal tail surfaces. In lateral displacements the flow about the wing opposite to the direction of slip was disturbed on the inner side, as shown by the woolen threads.

Observation of the flow about the wing led to the conclusion that tail flutter in straight flight is caused by separation of the flow on the upper wing surface, extending with decreasing impact pressure. Eddies are thereby developed which strike the horizontal tail surfaces and start fluttering vibrations.

In straight flight with idling engine, fluttering begins at much higher impact pressures than in straight flight with full throttle. The flow about the wing root swept by the propeller slipstream separates at larger angles of attack and smaller impact pressures owing to the increased velocity of flow. This result agrees with the above-mentioned flight and model test results obtained with Junkers F 13 airplanes.

Observations show that tail flutter in sideslips is due to separation of the flow from the wing and from the side of the fuselage. The separation is not, however, uniform on both wings, as with greatly raised elevator, but only on the wing turned away from the direction of slip. The reason is that, on low-wing monoplanes, the root of this wing is shielded by the fuselage. The vortices shed by the upper surface of the wing and, at large angles of slip, by the fuselage, strike one half of the horizontal tail surfaces, thus starting buffetting vibrations.

A disturbance of the flow on the upper surface of the wing near the fuselage was also observed throughout the wing chord under all flight conditions including small angles of attack. The disturbed region is narrow at the leading edge and increases considerably in width toward the trailing edge. This separation is attributable to the influence of the fuselage on the wing. The flow encounters increased pressure on the rear part of the upper surface of the wing, especially in the case of highly cambered wing sections. The kinetic energy of the flow is insufficient to overcome this increased pressure, and separation of the flow ensues. This occurs particularly when the wing and the side of the fuselage form a sharp angle, as in low-wing monoplanes, especially with fuselages of elliptical cross section.

III. POSSIBILITIES OF ELIMINATING TAIL BUFFETING

According to the results of qualitative investigations of the flow about the wing, elimination of tail flutter seems possible either by shifting the horizontal tail surfaces to a nonvortical region or by preventing premature separation of the flow at the wing root.

A strut with woolen threads, perpendicular to the plane of the horizontal tail surfaces, was secured to the experimental airplane forward of the leading edge of the fin. Observation of the threads during flight showed that the core of the vortices shed by the wing root at large angles of attack passed above the horizontal tail surfaces. Raising the tail would therefore have increased the buffeting, improvement in this respect being possible only by lowering the tail.

Various methods of preventing premature separation of the wing flow are outlined below (fig. 5):

a) Auxiliary airfoil on the upper surface of the wing. The nozzle effect of the slot between this airfoil and the wing causes the flow to adhere up to large angles of attack.

b) Flap on the trailing edge of the wing. The flap can be arranged to form a slot with the trailing edge. The negative pressure on the upper surface of the flap is intended to suck off the boundary layer from the upper surface of the wing at large angles of attack.

c) Flap forward of the leading edge (Handley Page type). The flap changes the course of the flow on the upper surface of the wing at large angles of attack. The closed flap is integral with the wing section. The flap opens automatically when the angle of attack of the wing exceeds a certain value.

d) Raising the trailing edge at the wing root. This deflection of the trailing edge changes the lift distribution throughout the span, thus relieving the wing root and retarding the separation of the flow in this region.

e) Fairing to form a transition from the side of the fuselage to the upper surface of the wing, designed to improve the conditions of the flow. Separation at the wing root under the influence of the fuselage can be prevented by suitable fairings.

f) Removal of the boundary layer from the upper surface of the wing by suction. By means of a blower, the vortical region, which develops at large angles of attack on the rear portion of the upper surface of the wing, is sucked into the wing through slots.

g) Blowing the boundary layer off the upper surface of the wing. Compressed air is blown through slots in the upper surface of the wing, as shown in figure 5,g. The effect on the flow about the wing is similar to the effect of suction.

The methods described in paragraphs f and g (removal of boundary layer by suction and by blowing) have thus far been checked only by model tests (reference 2). No practical application has been made, owing to the high power required for the operation of the blower which is considered uneconomical. The methods described in paragraphs a to e have already been used with satisfactory results.

IV. TEST FOR THE ELIMINATION OF TAIL FLUTTER

1. Choice of Methods

The tail of the experimental BFW-M 23 b airplane cannot be lowered, owing to the shape of the rear end of the fuselage. Only by preventing premature separation of the flow at the wing root, can tail flutter be easily eradicated.

This result is most quickly achieved by fairing the angle between the side of the fuselage and the upper surface of the wing and by simultaneously raising the trailing edge at the wing root. Under the influence of the fuselage on the upper surface of the wing the flow is disturbed at the wing root. This region of disturbance, observed under all flight conditions, seems to facilitate separation of the flow from the wing at large angles of attack. Separation of the flow from the outer portion of the wing may be retarded by eliminating this zone of disturbance or by raising the trailing edge at the wing root.

2. Tests with Fairing I

a) Test procedure.- The fairing of the wing root was determined by testing models in the Göttingen wind tunnel (reference 3). The radius of curvature of the bent portion covering the angle between the fuselage and the upper surface of the wing was small at the leading edge and increased toward the rear* (fig. 6) designated as "fairing I" in the report. The fairing was of sheet aluminum stiffened internally by ribs. It was riveted to the wing and fuselage. The wing fuselage connections, both without and with fairing I, are shown in figures 7 and 8, respectively. The portion of the trailing edge extending below the bottom of the fuselage was cut off and the lower surface of the wing was raised to the second rib. A sheet fairing formed a gradual transition from the fuselage bottom to the lower surface of the wing (figs. 9 and 10). The weight of the whole fairing was 6 kg (13.2 lb.). After making these changes, the flow about the wing was again subjected to a qualitative investigation. The woolen threads and

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*A fairing of similar design was used by the Akademische Fliegergruppe, Berlin, on their Junkers "Junior" airplane entered for the 1931 Deutschlandflug (Circuit of Germany). Flight characteristics and performances were improved by the fairing. (See also reference 4.)

the tail unit were observed under the same flight conditions as without fairing.

<u>b) Test results.</u>- Up to about 110 km/h (68 mi./hr.) the flow conformed satisfactorily throughout the whole wing in straight flight with idling engine. Separatiom, as shown in figure 11, occurred when the speed dropped to about 85 km/h (53 mi./hr.) (c_a = 1.4.) The flow always conformed to the fairing. Tail flutter, due to separation of the flow from the wing, occurred at no impact pressure. Slight high-frequency vibrations of the tail occurred at approximately 100 km/h (62 mi./hr.). They vanished completely when the elevator was raised further. The double amplitude of the stabilizer tip was about 1 centimeter. These vibrations are attributable to the agreement between the natural oscillation period of the wing-fuselage unit and of the engine at the given idling r.p.m. Oscillations were eliminated by a slight adjustment of the throttle.

In straight flight at full throttle the flow conformed satisfactorily up to 100 km/h. Further raising of the elevator caused separation of the flow from the wing. With decreasing speed the boundary of the region of separation traveled toward the wing tip (fig. 12). The flow always conformed to the fairing. Tail buffeting occurred at no impact pressure.

In right- and left-hand turns and spirals with full throttle or idling engine the tail unit was quiet, regardless of inward or outward slipping. In pronounced sideslips with rudder fully deflected to the left or right and engine running at full throttle, the tail unit was likewise quiet, whereas slight fluttering occurred in slips with idling engine. The double amplitude of the stabilizer tip was about 1 cm (0.4 in.). The boundary between the region of separation and that of conforming flow in sideslips to the right with idling engine is shown in figure 13.

According to the investigation, the flow conformed to the wing-root fairing in straight flight with full throttle or idling engine under all impact pressures and in turns and spirals with slight sideslips. In rectilinear flight at small impact pressures a wedgelike region of disturbance developed on the outer portion of the wing. At the same flying speed, the area of the disturbed regions was reduced by fairing I. No tail flutter occurred in straight, curvilinear and spiral flights, indicating that, without fairing, tail flutter is due chiefly to the vortices shed by the wing root. In test flights with fairing I, slight fluttering occurred only in sideslips with idling engine. The landing characteristics of the airplane were materially improved by the fairing. The flow adhered to the horizontal tail surfaces until the airplane reached the ground.

3. Tests with Fairing II

a) Test procedure.- The form of fairing I, used in the first test, was difficult to produce and its high cost makes its general adoption doubtful. It was therefore decided to test another fairing which would be less expensive and easier to produce. The conditions of low cost and simplicity of design are most easily fulfilled by a fairing capable of being geometrically developed. The improved performances obtained with fairing I appear to be due to the increased chord at the wing root rather than to the rounded wing-fuselage connection. For a given lift distribution, the deep transitional portion has a smaller lift coefficient, and the separation is retarded in this region.

The simplified fairing designed by Professor Madelung, of Stuttgart, is shown in figure 14. Its forward portion merely covers the angle between the wing and fuselage, while its after portion represents material increases in the thickness and chord of the wing section. The fairing of the lower surface of the wing, which forms a gradual transition to the bottom of the fuselage, is the same as used with fairing I.

Several flights were made with the experimental airplane BFW-M 23 b equipped with this simplified fairing. The flow distribution on the upper surface of the wing and about the tail unit was observed during these tests in various positions of flight.

b) Test results.- The displacements of the boundary of the region of separation at various speeds in straight flight with idling engine are shown in figure 15. Even at very small angles of attack the woolen thread at the observation point 9 was disturbed. With decreasing speed, the region of separation extended triangularly toward the wing tips and the fuselage. At approximately 80 km/h (50 mi./hr.) it reached the inner end of the aileron at the trailing edge. Flutter of the horizontal tail surfaces occurred at no impact pressure.

Similar conditions were found in tests with full throttle at various speeds in straight flight. The flow conformed up to large angles of attack under the influence of the propeller slipstream. At all speeds, a slight separation of the flow occurred at the trailing edge near the fairing. A greater separation was observed only at speeds below 85 km/h. The extension of the region of separation is shown in figure 16. Tail flutter occurred at no speed. Even in right and left turns and spirals and in sideslips with full throttle or idling engine the horizontal tail surfaces remained quiet.

The photographs in figures 17 to 19 were taken with a camera carried in the pilot's cockpit of the experimental airplane. Figure 17, taken at 140 km/h (87 mi./hr.) in flight with full throttle shows the distribution of the flow over the upper surface of the wing as indicated by red and white woolen threads. The direction and tautness of the woolen threads indicate adherence of the flow throughout the span of the wing. Figures 18 and 19, illustrating the flow at speeds of 85 and 80 km/h, respectively, show larger regions of separation which extend with decreasing flight speed from the wing root toward the tips.

According to the results of flow investigations at the wing root with fairing II, the expansion of the region of separation was about the same as with fairing I. At large angles of attack the flow separated from fairing II, whereas it always adhered to fairing I. No tail flutter occurred, either in straight, curvilinear and spiral flight, or in sideslips.

V. INFLUENCE OF FAIRING I ON THE PERFORMANCES

A determination of the polar, when thrust = drag, was attempted by flight measurements for the purpose of comparing the performances of the experimental airplane with and without fairing I. A few preliminary tests showed, however, the difficulty of accurately determining the power of the Argus As 8 air-cooled in-line engine on the torque stand. The absence of relative wind in torque-stand tests caused continual variation of the thermal conditions of the engine, which materially affected its power. This method was therefore dispensed with, and the tests were confined to the determination of the maximum speed and of the climbing and downward vertical velocities at various flight speeds.

The maximum speed was determined in quadrangular flight at 80 m (262 ft.) above the ground. Each portion of the course had a length of 4,560 and 2,980 m (2.83 and 1.85 miles). The maximum speed in quadrangular flight was 167.8 km/h (104 mi./hr.) without fairing and 172.4 km/h (107 mi./hr.) with fairing I. The measured difference was therefore 4.6 km/h (3 mi./hr.).

A certain number of climbs with full throttle and glides with idling engine were made at different flight speeds for the determination of the climbing speed and rate of vertical descent. The air speed was determined by an Askania static air-speed recorder; altitude variations and the fore-and-aft inclination by a combined recording altimeter and fore-and-aft inclinometer. The ascending and descending vertical velocities, with and without fairing I, are plotted in figure 20 against the actual flying speed.

The scattering of the points is due to several influences. The results of climbing and downward vertical velocity measurements are particularly affected by vertical motions of the air, by the variable relation between the specific weight of the air and the altitude and by variations of the engine power with the density of the air. Under these conditions a great number of points, measured in flight, are required for the determination of a mean value. The relation between the lift coefficient and the angle of fore-and-aft inclination, with and without fairing I, is plotted in figure 21.

VI. SUMMARY

In accord with earlier tests, made by the D.V.L. with Junkers F 13 airplanes, the investigation of the flow about the wing of a BFW-M 23 b airplane showed that tail flutter in straight flight is due to separation of the flow from the upper surface of the wing, this separation extending toward the wing tip with decreasing impact pressure. Tail flutter in sideslips is attributable to a separation of the flow from the fuselage and from the wing turned away from the direction of slip. Moreover, it was observed that the flow on the upper surface of the wing was disturbed under all flight conditions near the fuselage. This region of disturbance, attributable to the influence of the fuselage on the wing, seemed to facilitate the separation of the flow from the wing at large angles of attack. For the

purpose of eliminating this region of separation, the wing was provided with a fairing to round off the angle between the side of the fuselage and the upper surface of the wing.

Flow investigations with fairing I showed that the flow conformed to the fairing at all impact pressures in straight flight and that no tail flutter occurred under these conditions. Only a slight fluttering was observed in sideslips with idling engine.

The construction of fairing I was difficult and expensive. The second investigation consisted therefore in testing a simpler and cheaper fairing mounted on the BFW-23 b airplane. Even with this simplified fairing II, no buffeting of the horizontal tail surfaces occurred in test flights. In consideration of these results, such fairings are recommended for the BFW-M 23 b airplanes now in service.

A comparison of the performances of the experimental airplane, with and without fairing I, shows that the influence of the fairing on horizontal and climbing speeds is small and does not exceed the allowable discrepancies of measurement.

Translation by W. L. Koporindé, Paris Office,
National Advisory Committee
for Aeronautics.

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FIGURE 1.- BFW-M 23 b monoplane. Red woolen threads attached to left wing for flow investigations.

FIGURE 3.- Boundaries of regions of separation at various indicated speeds in straight flight with idling engine and unfaired wing root. Tail flutter began at about 110 km/h and below.

FIGURE 4.- Boundaries of the regions of separation at various recorded speeds in straight flight with full throttle and unfaired wing root. Tail flutter began at about 90 km/h (56 mi./hr.) and below.

FIGURE 6.- Wing-fuselage connection. Bent iron wires are fitted to the wing and fuselage to indicate the proposed shape of fairing I and to facilitate its construction. The metal sheet was shaped to this pattern.

FIGURE 7.- Wing-fuselage connection without fairing.

FIGURE 8.- Wing-fuselage connection with fairing I. The radius of curvature of the fairing between the fuselage and the upper surface of the wing increases from the leading edge toward the rear.

FIGURE 9.- Lower surface of wing before fairing was added. The highly cambered lower surface of the wing makes a sharp angle with the bottom of the fuselage. The trailing edge at the wing root extends below the bottom of the fuselage.

FIGURE 10.- Lower surface of wing with fairing I. The fairing forms a gradual transition from the lower surface of the wing to the bottom of the fuselage. The trailing edge extending below the bottom of the fuselage is cut off and the lower surface of the wing is raised to the second rib.

FIGURE 11.- Boundaries of the regions of separation at various indicated speeds in rectilinear flight with idling engine and fairing I. Tail flutter occurred at no impact pressure. The area of the disturbed regions for equal velocities was reduced by the fairing.

FIGURE 12.- Boundaries of the regions of separation at various indicated speeds in straight flight with full throttle and fairing I. Tail flutter occurred at no impact pressure.

FIGURE 13.- Boundaries of the regions of separation in a sideslip to the right with idling engine and fairing I. Slight tail flutter occurred in this case.

FIGURE 14.- Wing-fuselage connection with fairing II. The form of the fairing can be developed geometrically. Its forward portion covers the angle between wing and fuselage, while the rear materially increases the thickness and chord of the wing section.

FIGURE 15.- Boundaries of the regions of separation at various indicated speeds in straight flight with idling engine and fairing II. Tail flutter occurred at no impact pressure. The region of separation spreads triangularly with decreasing speed.

FIGURE 16.- Boundaries of the regions of separation at various indicated speeds in straight flight with full throttle and fairing II. Flutter of the horizontal tail surfaces occurred at no impact pressure.

FIGURE 17.- Flow on upper surface of wing in flight at about 140 km/h with full throttle and fairing II is shown by woolen threads. The threads are taut and point rearward. The flow adheres throughout the span.

FIGURE 18.- Flow with idling engine at about 85 km/h with fairing II. The threads of the wing root and trailing edge are disturbed and begin to flutter. The flow partially separates in this region.

FIGURE 19.- Flow with idling engine at 80 km/h (49.7 mi./hr.) with fairing II. The separation of the flow progresses. Some of the threads at the wing root point forward, indicating complete separation of the flow. On the outer portion of the wing the flow separates only at the trailing edge. The threads of the rearmost row are just beginning to turn forward.

FIGURE 20.- Ascending and descending vertical velocities plotted against the airplane speed, with and without fairing I.

FIGURE 21.- Lift coefficient plotted against angle of fore-and-aft inclination, with and without fairing I.

Figure 1.

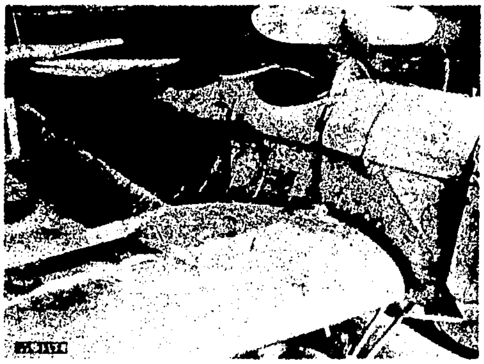


Figure 6.

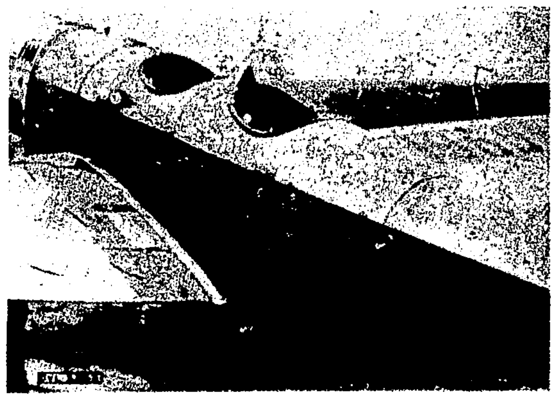


Figure 7.

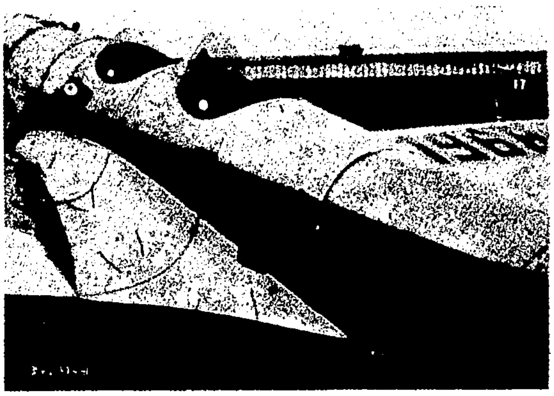


Figure 8.

Figure 9.

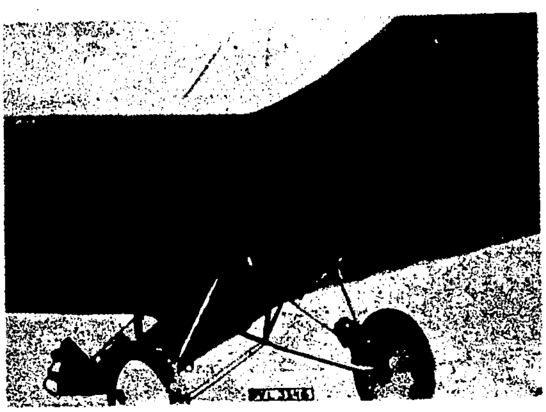


Figure 10.

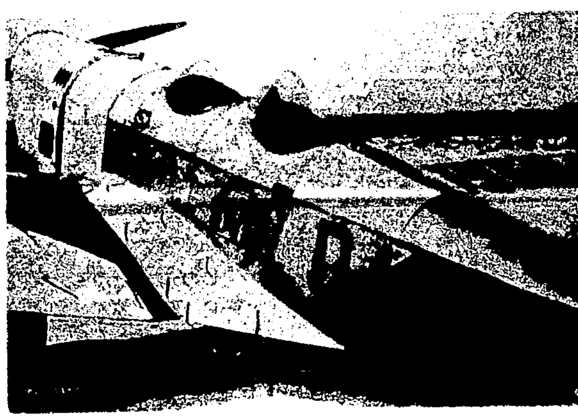
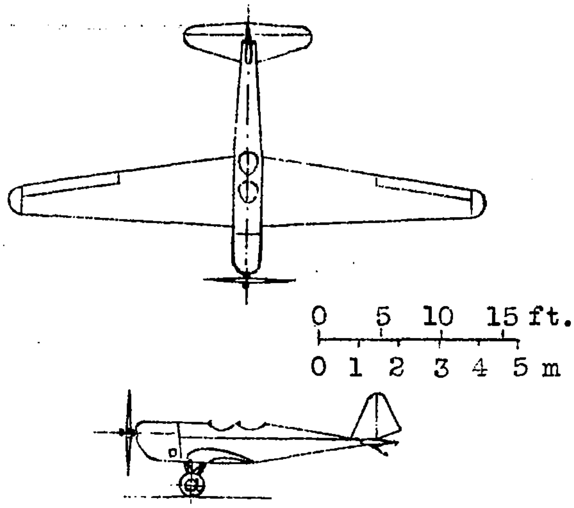


Figure 14.



Year of construction		1930
Engine type		Argus As 8/II
Engine power		90 hp
Propeller	D=2500 mm	8.2 ft.
	R=1320 "	4.3 "
Span	b=11.8 m	38.7 "
Mean chord	t_m=1.34"	4.4 "
Wing area, F=14.7 m^2,		158.2 sq.ft.
Weight empty (equipped)		
	G_R=380 kg	838 lb.
Total weight during investigation of flow about the wing		
	G_R=600 kg	1323 lb.
Total weight during performance tests	G_R=527 kg	1162 lb.

Figure 2. - General arrangement drawings of BFW-M 23 b monoplane.

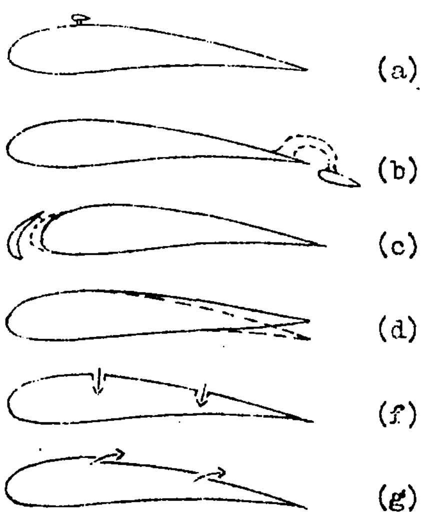


Figure 5. - Various means of preventing premature separation of the flow about the wing.

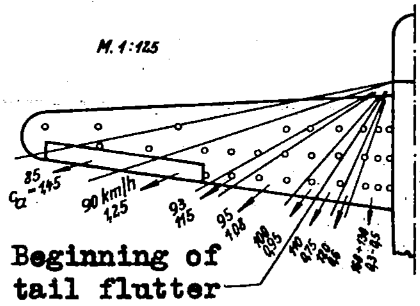


Figure 3.

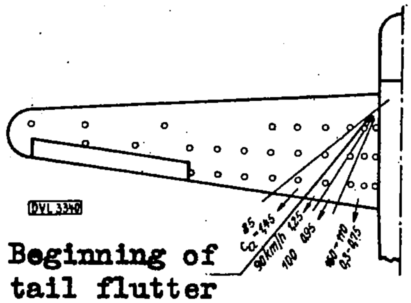


Figure 4.

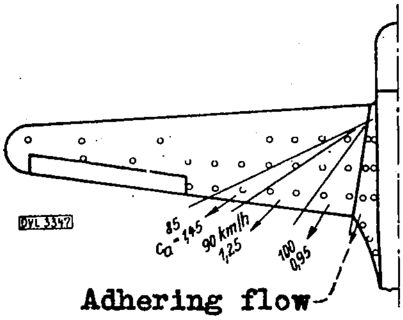


Figure 11.

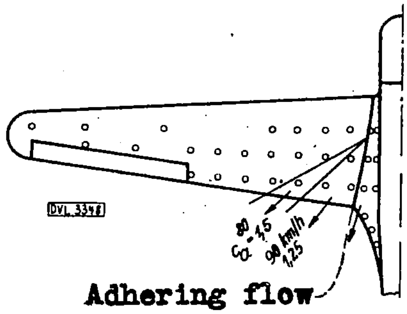


Figure 12.

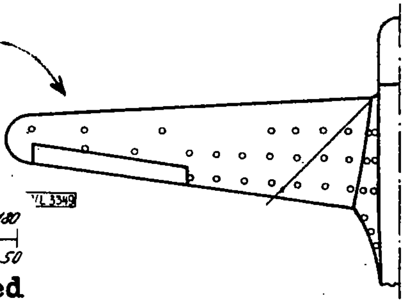


Figure 13.

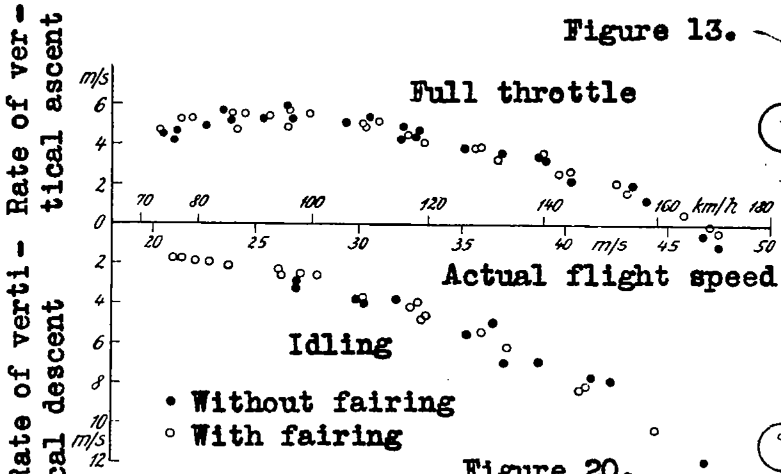


Figure 20.

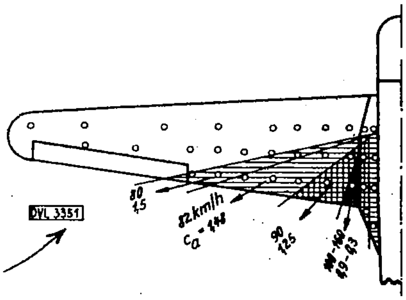


Figure 15.

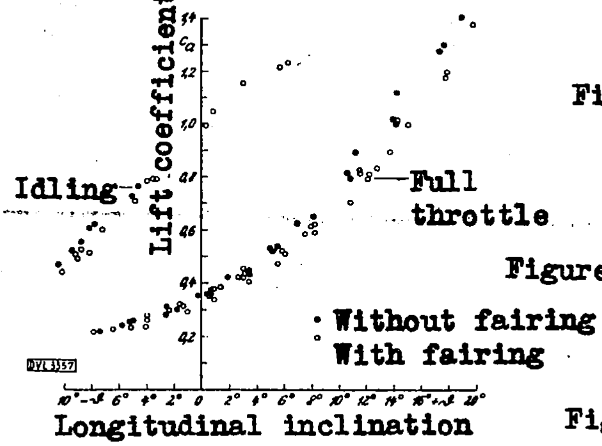


Figure 21.

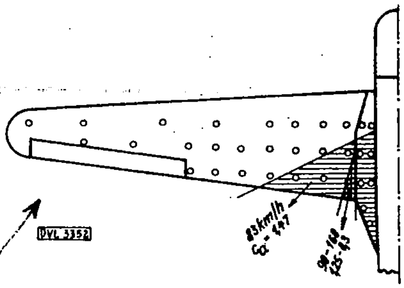


Figure 16.

Figure 17.

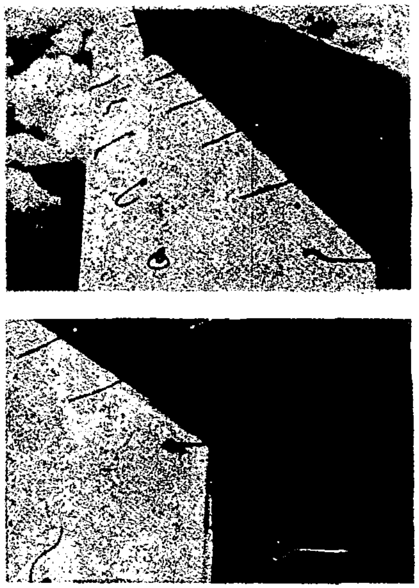


Figure 18.

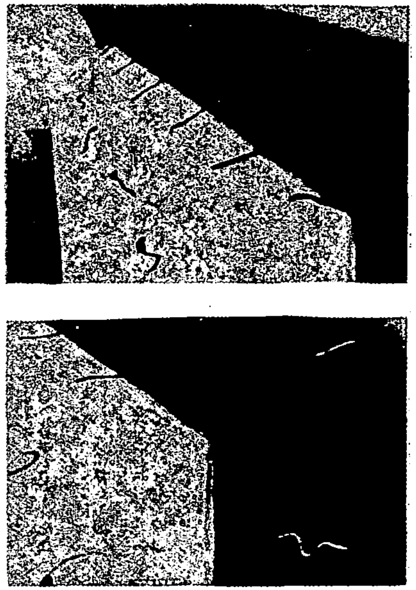


Figure 19.